PCT

WORLD INTELLECTUAL PROPERTY ORGANIZATION
International Bureau

INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G11B	A2	(11) International Publication Number: WO 95/26547 (43) International Publication Date: 5 October 1995 (05.10.95)

(21) International Application Number: PCT/IB95/00124

(22) International Filing Date: 1 March 1995 (01.03.95)

(30) Priority Data:
94200807.9 25 March 1994 (25.03.94) EP
(34) Countries for which the regional or international application was filed: AT et al.

(71) Applicant: PHILIPS ELECTRONICS N.V. [NL/NL]; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(71) Applicant *(for SE only)*: PHILIPS NORDEN AB [SE/SE]; Kottbygatan 5, Kista, S-164 85 Stockholm (SE).

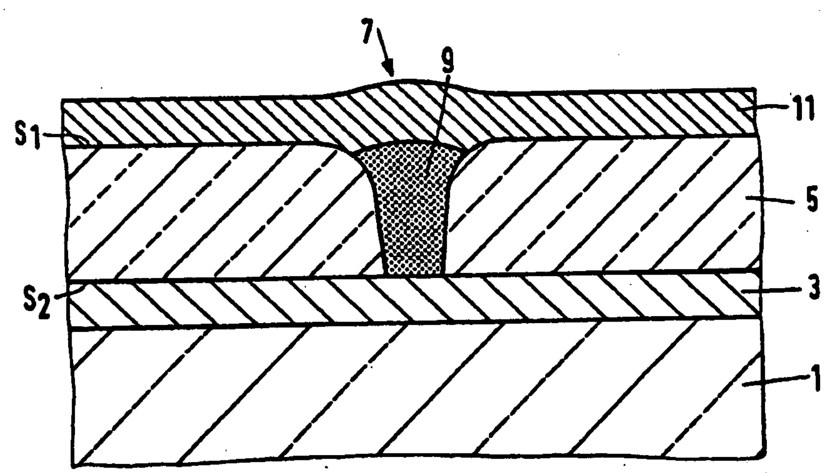
(72) Inventors: SCHÖNENBERGER, Christian; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL). GIJS, Martinus, Adela, Maria; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL). GIESBERS, Jacobus, Bernardus; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL). PALS, Jan, Albertus; Groenewoudseweg 1, NL-5621 BA Eindhoven (NL).

(74) Agent: WEENING, Cornelis; Internationaal Octrooibureau B.V., P.O. Box 220, NL-5600 AE Eindhoven (NL).

(81) Designated States: JP, KR, SG, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
Without international search report and to be republished upon receipt of that report.

(54) Title: MAGNETO-RESISTIVE DEVICE, AND MAGNETIC HEAD COMPRISING SUCH A DEVICE



(57) Abstract

A magneto-resistive device comprising a magnetic multilayer structure (9) which is deposited within a connective passage (7) running between and emerging into two opposed surfaces (S_1, S_2) of a film (5), successive constituent layers of the multilayer structure (9) being located at increasing distance from one of these surfaces (S_1, S_2). Such a multilayer structure (9) is preferably deposited using electrochemical techniques, and can be incorporated into an ultra-magnetic head employing the so-called CPP measuring geometry.

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AT	Austria
AU	Australia
BB	Barbados
BE	Belgium
BF	Burkina Faso
BG	Bulgaria
BJ	Benin
BR	Brazil
BY	Belarus
CA	Canada
CF	Central African Republic
CG	Congo
CH	Switzerland
CI	Côte d'Ivoire
CM	Cameroon
CN	China
CS	Czechoslovakia
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GA	Gabon
GB	United Kingdom
GE	Georgia
GN	Guinea
GR	Greece
HU	Hungary
IE	Ireland
IT	Italy
JP	Japan
KE	Kenya
KG	Kyrgystan
KP	Democratic People's Republic of Korea
KR	Republic of Korea
KZ	Kazakhstan
LI	Liechtenstein
LK	Sri Lanka
LU	Luxembourg
LV	Latvia
MC	Monaco
MD	Republic of Moldova
MG	Madagascar
ML	Mali
MN	Mongolia
MR	Mauritania
MW	Malawi
NE	Niger
NL	Netherlands
NO	Norway
NZ	New Zealand
PL	Poland
PT	Portugal
RO	Romania
RU	Russian Federation
SD	Sudan
SE	Sweden
SI	Slovenia
SK	Slovakia
SN	Senegal
TD	Chad
TG	Togo
TJ	Tajikistan
TT	Trinidad and Tobago
UA	Ukraine
US	United States of America
UZ	Uzbekistan
VN	Viet Nam

"Magneto-resistiv device, and magnetic head c mprising such a device"

The invention relates to a magneto-resistive device comprising a magnetic multilayer structure.

The invention also relates to a method of manufacturing such a magneto-resistive device.

The invention further relates to a magnetic head incorporating such a device.

Magneto-resistance is that phenomenon whereby the electrical resistance measured along a given path within an appropriate material is found to be influenced by the presence of a magnetic field intersecting the material. The phenomenon can thus be exploited to transcribe probed magnetic field fluctuations into accurately measurable resistance variations within the material, thereby lending itself to application in fine magnetic field sensors and magnetic heads. Such magnetic heads can be used for transferring information to and from a magnetic recording medium, such as a magnetic tape, disc or card.

The magnitude of the magneto-resistance effect along a given path in a particular material can be defined by the formula:

$$MR = \frac{(R_0 - R_F)}{R_F} \qquad (1)$$

in which R_0 is the electrical resistance measured along the said path in the absence of a magnetic field, and R_F is the electrical resistance measured along the same path in the presence of a variable magnetic field. The value of MR is usually expressed as a percentage, and is preferably as large as possible so as to yield maximum attainable sensitivity in sensor applications such as those mentioned above.

A magneto-resistive device as hereabove described is elucidated in United States Patent US 5,134,533, in which the multilayer structure is disposed upon a planar non-conducting substrate, and comprises alternately-stacked thin layers of ferromagnetic material (preferably Fe, Co or Ni) and thin layers of non-magnetic material (preferably Cr, V or Ti),

the former being antiferromagnetically coupled across the latter and having an in-plane easy axis of magnetisation, the total thickness of the multilayer structure thus formed being of the order of a micron. The electrical resistance of a multilayer structure of this type can be measured by applying a known electrical voltage gradient in the plane of the substrate, thereby inducing a measurable lateral flow of electrical current across the multilayer structure, the ratio of the said electrical voltage and electrical current yielding the value of the electrical resistance. Such a measuring geometry is referred to as the Current-In-Plane (CIP) geometry. The resistance values thus measured, in both the absence and presence of an external magnetic field, can be employed to calculate the magneto-resistance effect using Formula (1) above. Typical values of the magneto-resistance effect thus attained with the known multilayer structure are of the order of 10%.

An alternative measuring geometry to the said CIP technique involves application of an electrical voltage gradient perpendicular to the constituent layers of the multilayer structure, thereby inducing a flow of electrical current which is also perpendicular to the layers. Calculations have suggested that, for a given multilayer structure, this so-called Current-Perpendicular-to-Plane (CPP) geometry will advantageously yield significantly higher magneto-resistance values than those obtained using the CIP procedure, by as much as a factor of five.

In the case of the known device, however, an inherent disadvantage of the CPP geometry compared to the CIP geometry is that absolute electrical resistances measured in the former case will be drastically lower than those measured in the latter case. The electrical resistance of the multilayer structure in a given direction is rendered by the formula:

$$R = \rho \left(\frac{L}{S}\right) \qquad (2)$$

in which ρ and L are the average electrical resistivity and length of the multilayer structure in the said direction, respectively, and S is the cross-sectional area of the multilayer structure perpendicular to the said direction. Considering a representative known multilayer structure deposited on a 2×2 mm^2 substrate and having a thickness of 1 μm, it is seen that:

- For the CIP geometry, L = 2 mm and S = 1 μm $\times$ 2 mm, so that (L/S) = 10^6 m^{-1};
- For the CPP geometry, L = 1 μm and S = 2 mm $\times$ 2 mm, so that (L/S) =0.25 m^{-1}.

In this case, therefore, CPP resistance values will be about a million times smaller than CIP values. Such drastically reduced resistance R will result in a significantly increased electrical

power consumption P, since $P = V^2/R$ at a given voltage V.

A trivial solution to this resistance problem is to simply increase the perpendicular thickness of the multilayer structure to macroscopic values approaching its lateral dimensions, thereby simultaneously increasing the perpendicular resistance of the multilayer structure. This, however, is an extremely inefficient, expensive and impracticable measure, in view of the lengthy and costly deposition processes and the relatively large quantities of (precious) metals which it necessitates. It is of little appeal as a viable solution.

An alternative solution, elucidated in articles by Gijs *et al.* in Phys. Rev. Lett. 70 (1993), pp 3343-3346 and Appl. Phys. Lett. 63 (1993), pp 111-113, achieves a reduction of the lateral dimensions of the multilayer structure by employing special etch-structuring techniques. The resulting multilayer structure is referred to as a "pillar", since its lateral dimensions are roughly of the same order of magnitude as its perpendicular thickness (both being of the order of a micron), thereby resulting in very significantly increased CPP electrical resistances relative to conventional multilayer structures. A disadvantage of such pillars, however, is that the special structuring techniques employed in their manufacture are both expensive and time-consuming, especially when particularly large (L/S)-ratios are desired.

It is an object of the invention to provide a practical magneto-resistance device having a multilayer structure which demonstrates a large magneto-resistance effect for the CPP geometry, without the absolute electrical resistances thus measured being undesirably small. It is a further object of the invention that such a device should be relatively easy and inexpensive to manufacture.

According to the invention, this and other objects are achieved in a magneto-resistance device comprising a magnetic multilayer structure, characterised in that the multilayer structure is deposited within a connective passage running between and emerging into two opposed surfaces S_1 and S_2 of a film, successive constituent layers of the multilayer structure being located at increasing distance from one of these surfaces.

The term "connective passage" as here employed is intended to denote such features as narrow penetrative holes, tunnels, pores, *etc.* Passages of this type may be naturally present in the film or may be artificially enlarged or created therein by physical, chemical or chemo-physical means, such as lithography, chemical or physical etching, ablation, radiative bombardment, particle bombardment, mechanical replication processes

(such as pressing), *etc.* There may, of course, be a plurality of such passages present in the film. It is not necessary that such passages have a constant cross section, n r that they are straight, nor that they are substantially perpendicular to the surfaces of the said film. In principle, passages in the form of splits and cracks are also suited to application of the inventive insights hereafter discussed.

By disposing successive constituent layers of the multilayer structure at increasing distance from one of the surfaces S_1, S_2, it is ensured that an electrical current traversing the multilayer structure from, say, S_1 to S_2 will be forced to flow in a direction substantially perpendicular to each said constituent layer. In this way, exploitation of the CPP geometry (instead of the CIP geometry) is ensured.

The material from which the film is comprised is preferably a poor electrical conductor, such as an electrical insulator or semi-conductor. Alternatively, in the case of an electrically conductive film material, the internal surface of the passage and relevant portions of the surfaces S_1 and S_2 should be thinly coated with an electrically insulating substance (such as quartz). In either such case, an electrical current fed to the multilayer structure *via* contacts at its extremities will be forced to flow (substantially perpendicularly) through the multilayer structure itself, rather than bypassing it through the surrounding film material.

To allow easy formation of electrical contacts, the film is preferably sandwiched between two relatively thick, smooth, flat-faced bodies of highly conductive material. Such bodies may, for example, be embodied as thin metallic plates or as metallic layers (deposited on bulk substrates).

Particular examples of films suitable for implementation in the inventive device include:

- Organic films (*e.g.* of polyimide or photoresist) in which holes have been created using, for example, a reactive ion etching process. The inventors have successfully prepared such films with passage diameters as low as 100 nm. Further information with regard to the well-known fine-scale etching techniques thereby employed is contained (for example) in an article by Gijs *et al.* in Appl. Phys. Lett. 59 (1991), pp 1233-1235;
- So-called Nuclepore™ filters, which are commercially available from Poretics Corp., California, USA. These filters consist of a thin plastic film which has been irradiated with high-energy particles and subsequently treated with a chemical etchant. The irradiation process induces damage tracks in the film,

which are then etched away so as to expose well-defined pores. The diameter of such pores typically ranges from a few nanometers to several microns.

An immediate advantage of the inventive device is that a narrow multilayer structure can be grown directly within the said passage; it is not necessary to first grow a large-scale structure and then subsequently etch it down to a pillar structure of drastically reduced lateral dimensions. Another advantage is that, even in the case of passages of submicron width, electrical contact can easily be made (*via* the surfaces S_1 and S_2) with the extremities of the multilayer structure therein located; in contrast, the provision of electrical contacts with the extremities of an etch-structured pillar of sub-micron width is extremely difficult, apart altogether from the fact that the pillar itself is exceptionally difficult and expensive to manufacture in the first place. Multilayer structures of submicron width have the considerable advantage that their CPP electrical resistances are relatively large (typical order of magnitude 10-100 Ω).

A preferential embodiment of the device according to the invention is characterised in that the constituent layers of the multilayer structure have an average width w_m measured parallel to S_1, and a cumulative thickness t_m measured perpendicular to S_1, whereby $w_m/t_m \leq 10$. The larger the value of w_m (for a given value of t_m), the smaller will be the measured CPP resistances for the multilayer structure concerned (see Formula (2)). The inventors have observed that, for $t_m \approx 1\ \mu m$ (a typical and practical multilayer thickness), measured CPP resistances become impractically small when $w_m > 10\ \mu m$, making the detection of subtle magneto-resistance effects extremely difficult (and also leading to increased electrical power consumption). It is therefore advantageous to minimise the ratio w_m/t_m, either by decreasing w_m (narrower passage) or increasing t_m (longer passage). Particularly satisfactory and reliable results are obtained when $w_m/t_m \leq 2$, yielding typical CPP resistances of the order of 50 Ω. The inventors have successfully manufactured several test devices in which $w_m \approx 0.2\text{-}0.3\ \mu m$ and $t_m \approx 1\ \mu m$, yielding a ratio w_m/t_m in the range 0.2-0.3.

Another preferential embodiment of the inventive device is characterised in that the average thickness t_f of the film (measured perpendicular to S_1) does not exceed 10 μm, and preferably does not exceed 2 μm. The thicker the film, the more difficult it is to create appropriate artificial passages in it using techniques such as lithography and etching. In addition, practical multilayer structures are typically about 1 μm thick, and it is not strictly necessary that the film in which they are located be substantially thicker. In cases whereby $t_f > t_m$, the portions of the passage which are not

occupied by the multilayer structure can be filled up with a highly conductive material such as Cu, Au, Ag, *etc.* Films for which t_f > 10 μm are, of course, also acceptable and suitable for use in conjunction with the invention.

The suitability of the inventive device for CPP operation is preferably complimented by an advantageous choice of magnetic multilayer structure. In this context, a particularly useful embodiment of the inventive magneto-resistive device is characterised in that the multilayer structure comprises at least one multiplet of metallic layers selected from the group formed by Fe/Cr/Fe, Co/Ag/Co, Co/Cu/Co, MnFe/NiFe/Cu/NiFe, $Ni_XFe_YCo_Z/Cu/Ni_{X'}Fe_{Y'}Co_{Z'}$, $Ni_XFe_YCo_Z/Ag/Ni_{X'}Fe_{Y'}Co_{Z'}$, $Ni_XFe_YCo_Z/Co/Cu/Co/Ni_{X'}Fe_{Y'}Co_{Z'}$, $Ni_XFe_YCo_Z/Co/Ag/Co/Ni_{X'}Fe_{Y'}Co_{Z'}$, and combinations thereof, whereby the individual values of X, Y, Z, X', Y' and Z' all lie in the range 0 to 1, and $X + Y + Z = 1 = X' + Y' + Z'$. These multiplets all demonstrate a large spin-valve magneto-resistance effect. The multilayer structure can, of course, comprise a plurality of such multiplets, either of a single type or of mixed types, and may also be deposited on a metallic buffer layer, if so desired. A full exemplary multilayer composition as here elucidated is discussed in more detail by Jimbo *et al.* in Jpn. J. Appl. Phys. 31 (1992), pp L1348-L1350.

The inventive device may, of course, comprise additional layers and multilayers, serving as oxidation barriers, insulation layers, electrical connection tracts, exchange-biasing structures, *etc.*

The invention also relates to a method of manufacturing a magneto-resistive device of the inventive type hereabove referred to. According to the invention, such a method is characterised in that the multilayer structure is deposited by an electrochemical deposition procedure. Since the multilayer structure must be deposited in a relatively narrow passage, a galvanic deposition method making use of a depository liquid is far more penetrative than techniques employing a directed depository flux of gaseous particles, such as sputter deposition or molecular beam epitaxy. In addition, electrochemical deposition is relatively cheap and fast, and is very suitable for the provision of relatively thick layers.

In an exemplary application of the inventive method, a 1-μm Au film is deposited on a smooth surface of a glass substrate, and subsequently covered with a 1-μm film of polyimide using a spin-coating process. With the aid of a reactive ion etch technique, the polyimide film is next provided with a well-defined, penetrative hole which extends perpendicular to its exposed surface. Using the Au film as a base electrode, a C /Cu multilayer is galvanically deposited in the hole, from solutions of Co and Cu salts. The

exposed polyimide surface is then pr vided with a further 1-μm film of Au. Since the polyimide film is electrically insulating, a voltage difference applied between th two Au "electrodes" will result in a flow of electrical current through the Co/Cu multilayer, in a direction substantially perpendicular to the constituent Co and Cu layers.

A preferential embodiment of the inventive method hereabove elucidated is characterised in that alternate layers in at least part of the multilayer structure are deposited from a single solution containing at least two species of metal ions, whereby the particular species deposited at any one time is determined by the chosen value of the applied electrical potential in the solution. Such a technique is described in relation to Cu/CoNiCu multilayers in an article by Alper *et al.* in Appl. Phys. Lett. 63 (1993), pp 2144-2146. The same method can, of course, be applied to achieve the deposition of other multilayer structures, provided the metallic materials of their various constituent layers (originating from the various metallic species present in the electrolyte) have different electronegative potentials. An immediate advantage of this particular method is that it saves time and expense, by removing the need to alternately change electrolytes between deposition of successive constituent layers of the multilayer structure.

In an alternative method of manufacturing the inventive device, the multilayer structure can be deposited in the passage using a Chemical Vapour Deposition (CVD) procedure.

Because of its intrinsically high sensitivity as a CPP sensor, the inventive magneto-resistive device is particularly suitable for incorporation in a magnetic head, as will be elucidated in more detail in the exemplary embodiments hereunder. A particular embodiment of such a magnetic head is characterised in that the magneto-resistive device is located in a gap between at least two magnetic flux guides which are disposed in hollows in a surface of the film. Such hollows can be provided using, for example, a lithographic technique, and can be subsequently filled with magnetic material using a variety of deposition methods, such as electrochemical, sputter and vapour deposition techniques. In this manner, a fully integrated ultra-thin magnetic circuit can be provided within the film.

The invention and its attendant advantages will be further elucidated with the aid of exemplary embodiments and the accompanying schematic drawings, not all of uniform scale, whereby:

Figure 1 is a cross-sectional view of part of a trilayer stack comprising a

polyimide film, being a suitable basis for manufacture of a magneto-resistive device according to the invention;

Figure 2 shows the subject of Figure 1 after provision of a connective passage therein;

In Figure 3, a multilayer structure has been deposited within the passage of Figure 2;

Figure 4 depicts the subject of Figure 3 subsequent to the provision of an electrically conductive layer thereupon;

Figure 5 renders a wider view of the inventive device shown in Figure 4, wherein supplementary wide connective passages have been provided;

Figure 6 shows the subject of Figure 5, after selective removal of parts of its covering electrically conductive layer;

Figure 7 gives a perspective view of a magnetic head incorporating a magneto-resistance device according to the invention;

Figure 8 renders a partial perspective view of a quadrilayer stack comprising a selectively etched polyimide film, being a suitable basis for integrative manufacture of an inventive magneto-resistive device with proximal magnetic flux guides;

Figure 9 is a partial cross-sectional view of the subject of Figure 8, taken along the line AA', subsequent to enaction of additional processing steps;

Figure 10 is a highly schematic cross-sectional depiction of a film provided with various connective passages wherein multilayer structures of various forms have been deposited in accordance with the invention.

Embodiment 1

Figures 1-4 depict various stages in the manufacture of a magneto-resistive device according to the present invention. Identical parts in the various Figures are denoted by the same reference symbols.

In Figure 1, a flat-faced substrate 1 has been successively provided with an electrically conductive layer 3 and a polyimide film 5. Suitable exemplary materials for the substrate 1 and layer 3 are glass and copper, respectively. The layer 3 can be provided by sputter deposition, and the film 5 can be provided by spin coating, for example. In this particular instance, the approximate thicknesses of the layer 3 and film 5 are 400 nm and $t_f = 1\ \mu m$, respectively. The layer 5 is delimited by surfaces S_1 and

S_2.

In Figure 2, a connective passage 7 has been created in the layer 5. This passage 7 runs between and emerges into the surfaces S_1 and S_2, and can be created using well-known lithographic and etching techniques, such as those elucidated (for example) by Gijs *et al.* in Mat. Res. Soc. Symp. Proc. 313 (1993), pp 11-21, in particular page 12. The average width of the passage 7 is about 0.6 μm.

As here depicted, the passage 7 is substantially straight and perpendicular to S_1. This is not strictly necessary however, and a curved or canted passage can also be used in conjunction with the invention.

In Figure 3, a multilayer structure 9 demonstrating a large spin-valve magneto-resistance effect (*e.g.* a repeated arrangement of alternated 16-Å layers of $Ni_{20}Fe_{80}$ and 19-Å layers of Cu) has been deposited within the passage 7. The multilayer structure's constituent layers (not shown here) are stacked in a direction substantially perpendicular to S_1 (so that successive constituent layers are thus located at increasing distance from S_1 or S_2, depending on the order in which they are counted). The multilayer structure 9 may be deposited electrochemically, using the layer 3 as a base electrode.

As here depicted, the multilayer structure 9 fills the passage 7 almost completely. This is not strictly necessary, however, and "filler" layers of conductive material may alternatively be disposed on either side of a thinner multilayer structure, if so desired.

Figure 4 depicts the subject of Figure 3 after provision of an electrically conductive layer 11 upon the film 5 and multilayer structure 9. In this instance, the layer 11 has a thickness of about 400 nm, comprises a metallic material such as Au, and is provided by sputter or vapour deposition.

The resulting inventive magneto-resistive device can be employed in the CPP mode by measuring the electrical resistance between the layers 3 and 11. Exemplary Embodiment 2 herebelow describes a scenario in which such measurement is greatly facilitated.

Embodiment 2

Figures 5 and 6 give a wider view of the device shown in Figure 4, wherein supplementary features have been provided. Identical parts in the Figures are denoted by the same reference symbols, which are also consistent with those used in Figures 1-4.

In Figure 5, the film 5 has been provided with additional structures 13, 15

on either side of the original multilayer structure 9. These additional structures 13, 15 have the same constitution as the multilayer structure 9, but are disposed in connective passages which are substantially wider (*e.g.* a factor ten) than the original passage 7. The film 5 is once again covered with a metallic layer 11.

In Figure 6, the layer 11 has been divided into (at least) three electrically isolated "islands" 21, 23, 25 by removal of intervening portions 17, 19 (using lithographic techniques, for example). Electrical contact with the underside 27 of the multilayer structure 9 can now easily be made *via* the layer 3 and either of the structures 13, 15. In this way, all electrical contacts with the multilayer structure 9 can be made from one side of the layer 5, *e.g.* by attaching fine gold threads separately to island 21 and to at least one of the islands 23, 25 (use of both of the islands 23 and 25 advantageously facilitates measurement of the electrical resistance of the multilayer structure 9 *via* the well-known "four-point" measurement geometry). Since the structures 13, 15 are relatively wide, their CPP electrical resistance is advantageously low, being only a fraction of the CPP resistance of the multilayer structure 9.

It is not strictly necessary that the structures 13, 15 be embodied as multilayers having the same composition as multilayer structure 9. If so desired, the structures 13, 15 may comprise other metallic substances, not necessarily in multilayer form, but provision of such structures will involve extra steps in the total lithographic procedure.

Embodiment 3

Referring to Figures 2-4, it is also possible to manufacture an inventive magneto-resistive device in which the film 5 is a Nuclepore™ film as previously discussed hereabove. The remaining parts and aspects of such a device can be identical to those in Embodiment 1.

Embodiment 4

Figure 7 is a schematic perspective view of part of a magnetic head 31 comprising an inventive magneto-resistive device 33 with electrical connections 35. The head 31 further comprises flux guides 37, 39, 41, which are positioned relative to the device 33 so as to form a magnetic circuit therewith. The end faces 43, 45 form part of the pole face of the magnetic head 31, the magnetic gap 47 being located between said faces 43, 45.

If a magnetic medium, such as a magnetic tape or disc, passes before the faces 43, 45 in close proximity thereto, the magnetically-stored information on that medium

will generate a varying magnetic flux in the above-mentioned magnetic circuit. This varying flux is fed to the magneto-resistive device 33, where it is transcribed into electrical resistance variations measurable *via* the electrical connections 35.

The magnetic head may also contain an electrical coil, which can be employed in the recording of magnetic information on magnetic media.

Embodiment 5

Figures 8 and 9 show various aspects of a magnetic head comprising an inventive magneto-resistive device in conjunction with (partially) integrated magnetic flux guides. Identical parts in the two Figures are denoted by the same reference symbols.

Figure 8 is a partially perspective and partially cross-sectional view of a quadrilayer stack suitable for manufacture of a magnetic head according to the invention. The stack comprises a soft-magnetic substrate 2 which is successively provided with an electrically insulating layer 4, an electrically conductive layer 6 and a polyimide film 8. The layers 4 and 6 comprise, for example, quartz and copper, respectively. The substrate 2 comprises, for example, NiFe. The film 8 has been provided with a connective passage 10, which is located in a gap between two essentially triangular hollows 12, 14.

Figure 9 renders a cross-sectional view of the subject of Figure 8, taken along the line AA' therein, subsequent to enaction of a number of additional process steps. A multilayer structure 16 demonstrating a large spin-valve magneto-resistance effect (*e.g.* a NiFe/Cu multilayer as used in Embodiment 1 hereabove) has been deposited in accordance with the invention in the passage 10. In addition, the hollows 12, 14 have been filled with soft magnetic material 18, 18', after prior removal (*e.g.* by etching) of part of the layers 4, 6. As a result of this removal, the material 18' makes partial physical contact with the substrate 2, thereby forming a magnetic circuit 2, 18', 18.

After provision of appropriate electrical contacts, such a device can be employed as an ultra-small magnetic head, having pole faces 20, 22 and a magnetic gap 24. If so desired, the width of the gap 24 can be reduced using lithographic techniques.

In a particularly simple embodiment of this device, the material 18, 18' is embodied as a multilayer having the same constitution as, and deposited concurrently with, the multilayer structure 16.

Embodiment 6

With reference to Figures 7 and 8, it is possible to use the hollows 12, 14

to achieve an improvement in the effectiveness of the external flux guides 39, 41. By mitting the soft-magnetic layer 2 (and the insulating layer 4) from th quadrilayer stack in Figure 8, and by directly filling the hollows 12, 14 with soft-magnetic material, it is possible to create integrated tapering "pole pieces" in the film 8. Such pole pieces can serve to accurately focus magnetic flux from external flux guides (such as guides 39, 41 in Figure 7) into the passage 10 (and the therein deposited multilayer structure).

Embodiment 7

Figure 10 is a highly schematic cross-sectional depiction of a film 100 having opposed surfaces S_1 and S_2. The film 100 has been provided with connective passages 102, 104, 106, in which respective multilayer structures 112, 114, 116 have been deposited in accordance with the invention. The constituent layers of the various multilayer structures 112, 114, 116 are schematically depicted. Since a practical film is typically of the order of 1 μm thick, and since the individual constituent layers of practical multilayer structures are typically of the order of 1 nm thick, it is obvious that Figure 10 is not to scale. It is primarily included here for purposes of clarification.

The illustrated connective passages 102, 104, 106 and multilayer structures 112, 114, 116 demonstrate various possible features of a valid device according to the invention. For such a device, it should be noted that:

- The connective passage can be perpendicular to the film plane (as is the case for passages 102, 106), or can be canted with respect thereto (as is the case for passage 104);
- The constituent layers of the multilayer structure can be flat (as is the case for structures 112, 114), or can be curved (as is the case for structure 116). Such curvature can arise, for example, as a result of surface tension effects;
- The constituent layers of the multilayer structure do not have to be parallel to one of the surfaces S_1, S_2 (as is the case for structure 116);

It is clear for all three structures 112, 114, 116 that successive constituent layers therein are located at increasing distance from, for example, surface S_2.

CLAIMS:

1. A magneto-resistive device comprising a magnetic multilayer structure, characterised in that the multilayer structure is deposited within a connective passage running between and emerging into two opposed surfaces S_1 and S_2 of a film, successive constituent layers of the multilayer structure being located at increasing distance from one of these surfaces.

2. A magneto-resistive device according to Claim 1, characterised in that the constituent layers of the multilayer structure have an average width w_m measured parallel to S_1, and a cumulative thickness t_m measured perpendicular to S_1, whereby $w_m/t_m \leq 10$.

3. A magneto-resistive device according to Claim 2, characterised in that $w_m/t_m \leq 2$.

4. A magneto-resistive device according to any of the Claims 1-3, characterised in that the average thickness t_f of the film measured perpendicular to S_1 does not exceed 10 μm.

5. A magneto-resistive device according to Claim 4, characterised in that $t_f \leq 2\ \mu m$.

6. A magneto-resistive device according to any of the preceding Claims, characterised in that the multilayer structure comprises at least one multiplet of metallic layers selected from the group formed by Fe/Cr/Fe, Co/Ag/Co, Co/Cu/Co, MnFe/NiFe/Cu/NiFe, $Ni_XFe_YCo_Z/Cu/Ni_{X'}Fe_{Y'}Co_{Z'}$, $Ni_XFe_YCo_Z/Ag/Ni_{X'}Fe_{Y'}Co_{Z'}$, $Ni_XFe_YCo_Z/Co/Cu/Co/Ni_{X'}Fe_{Y'}Co_{Z'}$, $Ni_XFe_YCo_Z/Co/Ag/Co/Ni_{X'}Fe_{Y'}Co_{Z'}$, and combinations thereof, whereby the individual values of the alloy fractions X, Y, Z, X', Y' and Z' all lie in the range 0 to 1, and $X + Y + Z = 1 = X' + Y' + Z'$.

7. A method of manufacturing a magneto-resistive device as claimed in any of the preceding Claims, characterised in that the multilayer structure is deposited by an electrochemical deposition procedure.

8. A method according to Claim 7, characterised in that alternate layers in at least part of the multilayer structure are deposited from a single solution containing at least two species of metal ions, whereby the particular species deposited at any one time is determined by the ch sen value of the applied electrical potential in the solution.

9. A magnetic head comprising a magneto-resistive device according to any of the Claims 1-6.

10. A magnetic head according to Claim 9, characterised in that the magneto-resistive device is located in a gap between at least two magnetic flux guides which are disposed in hollows in a surface of the film.

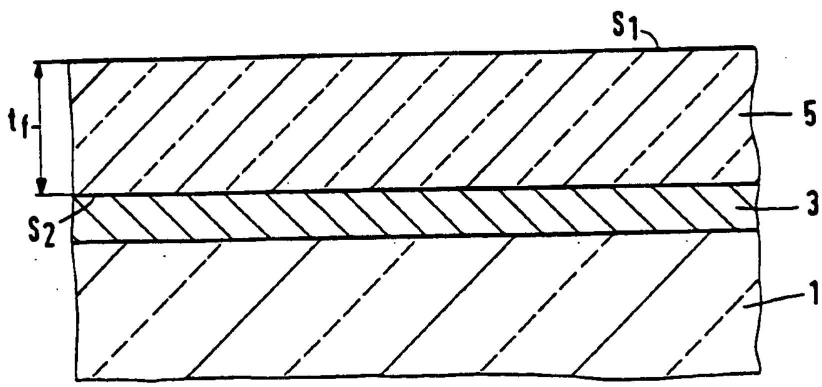


FIG.1

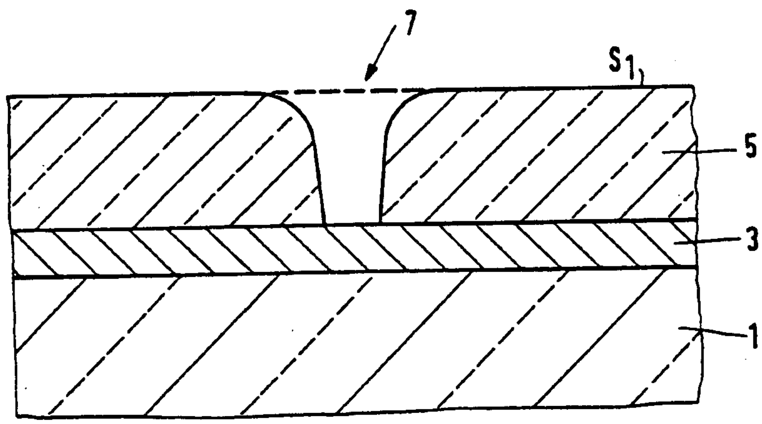


FIG.2

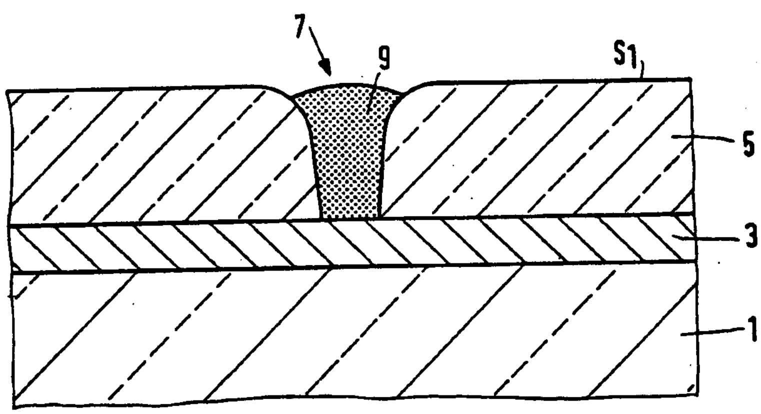


FIG.3

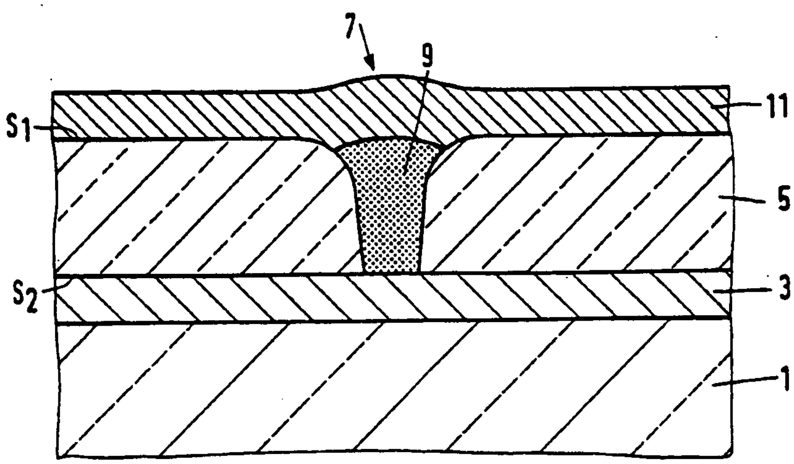


FIG.4

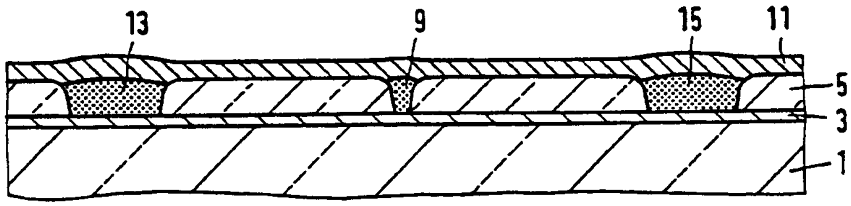


FIG.5

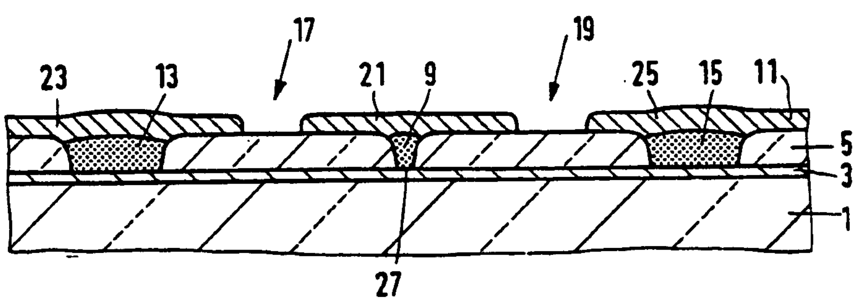


FIG.6

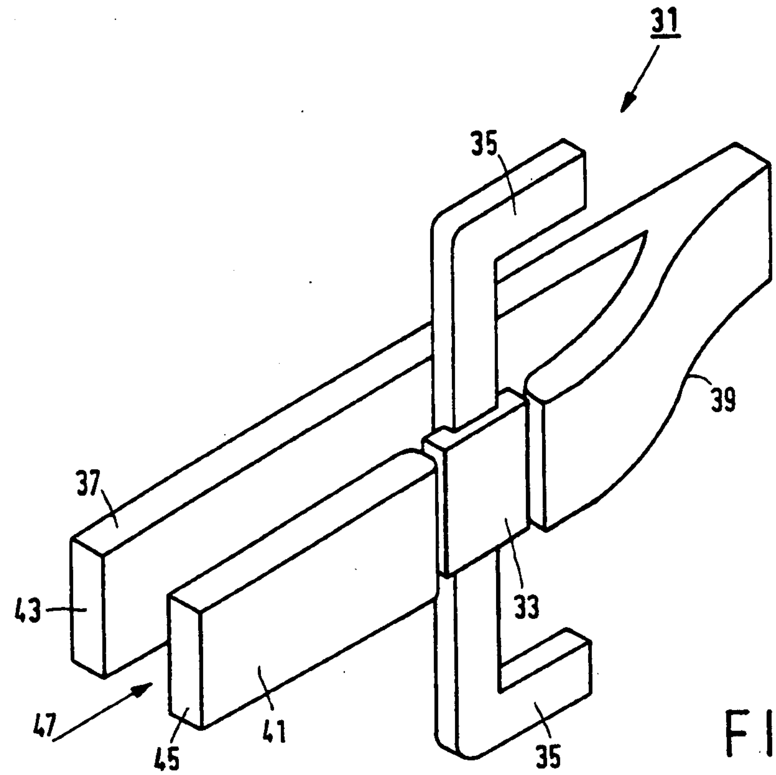


FIG.7

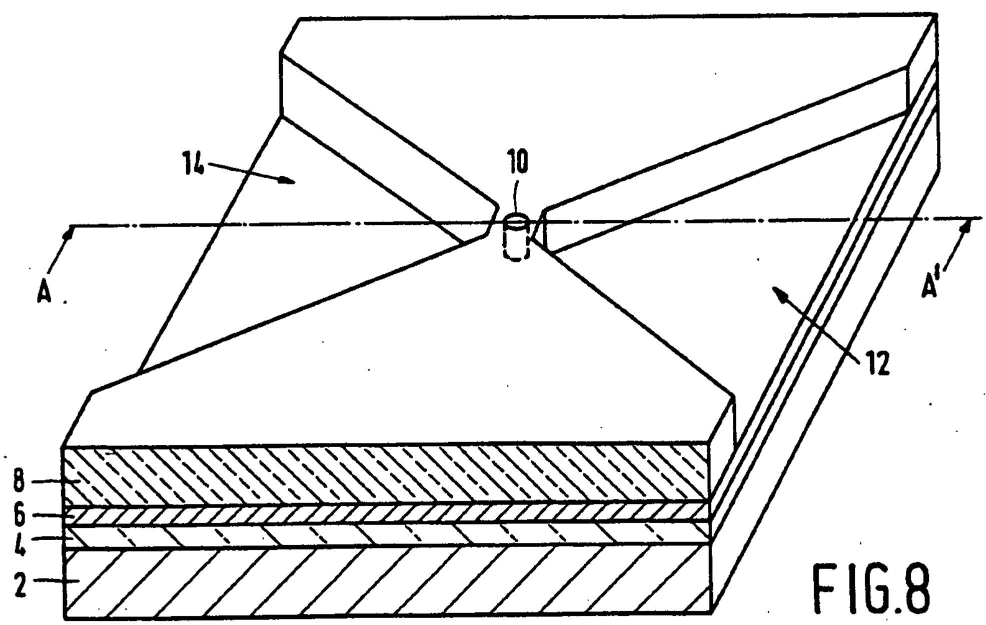


FIG.8

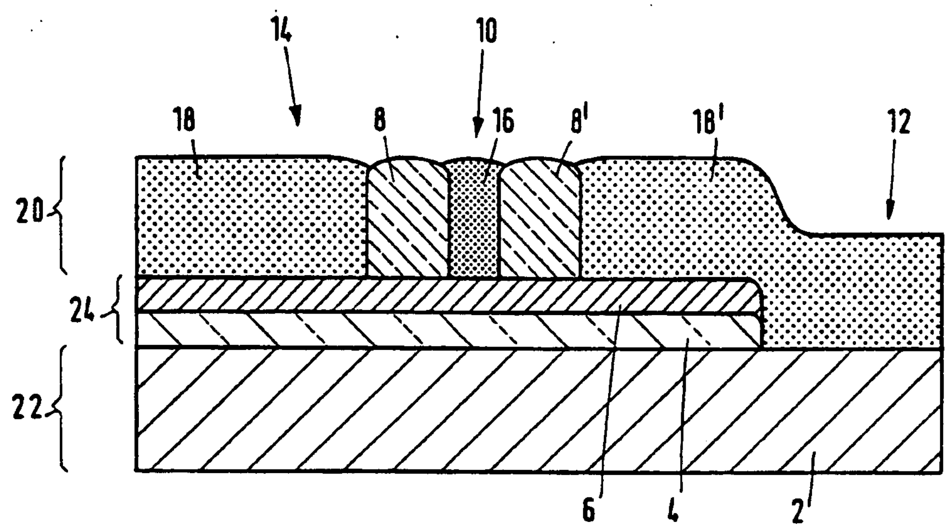


FIG.9

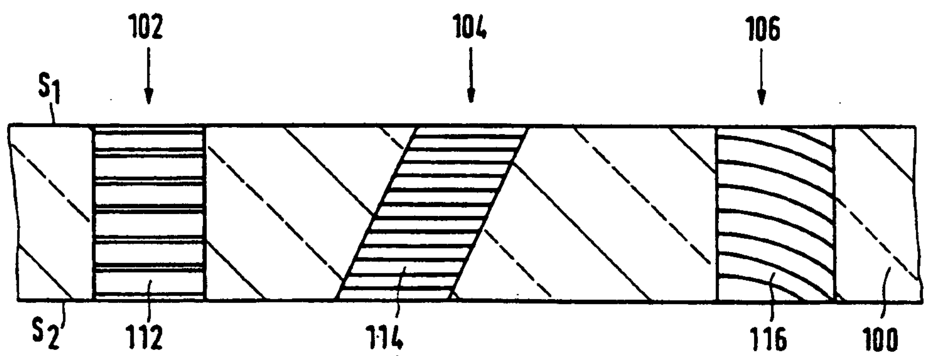


FIG.10